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SYSTEMS AND METHODS FOR DEPOSITING MATERIAL ONTO MICROFEATURE WORKPIECES IN REACTION CHAMBERS

TECHNICAL FIELD

[0001] The present invention is related to systems and methods for depositing material in thin film deposition processes used in the manufacturing of microfeatures.

BACKGROUND

[0002] Thin film deposition techniques are widely used in the manufacturing of microfeatures to form a coating on a workpiece that closely conforms to the surface topography. The size of the individual components in the workpiece is constantly decreasing, and the number of layers in the workpiece is increasing. As a result, both the density of components and the aspect ratios of depressions (i.e., the ratio of the depth to the size of the opening) are increasing. The size of workpieces is also increasing to provide more real estate for forming more dies (i.e., chips) on a single workpiece. Many fabricators, for example, are transitioning from 200mm to 300mm workpieces, and even larger workpieces will likely be used in the future. Thin film deposition techniques accordingly strive to produce highly uniform conformal layers that cover the sidewalls, bottoms, and corners in deep depressions that have very small openings.

[0003] One widely used thin film deposition technique is Chemical Vapor Deposition (CVD). In a CVD system, one or more precursors that are capable of reacting to form a solid thin film are mixed while in a gaseous or vaporous state, and then the precursor mixture is presented to the surface of the workpiece. The surface of the workpiece catalyzes the reaction between the precursors to form a

solid thin film at the workpiece surface. A common way to catalyze the reaction at the surface of the workpiece is to heat the workpiece to a temperature that causes the reaction.

[0004] Although CVD techniques are useful in many applications, they also have several drawbacks. For example, if the precursors are not highly reactive, then a high workpiece temperature is needed to achieve a reasonable deposition rate. Such high temperatures are not typically desirable because heating the workpiece can be detrimental to the structures and other materials already formed on the workpiece. Implanted or doped materials, for example, can migrate within the silicon substrate at higher temperatures. On the other hand, if more reactive precursors are used so that the workpiece temperature can be lower, then reactions may occur prematurely in the gas phase before reaching the substrate. This is undesirable because the film quality and uniformity may suffer, and also because it limits the types of precursors that can be used.

[0005] Atomic Layer Deposition (ALD) is another thin film deposition technique. Figures 1A and 1B schematically illustrate the basic operation of ALD processes. Referring to Figure 1A, a layer or partial layer of gas molecules A_x coats the surface of a workpiece W. The layer of A_x molecules is formed by exposing the workpiece W to a precursor gas containing A_x molecules and then purging the chamber with a purge gas to remove excess A_x molecules. This process can form a monolayer or partial monolayer of A_x molecules on the surface of the workpiece W because the A_x molecules at the surface are held in place during the purge cycle by physical adsorption forces at moderate temperatures or chemisorption forces at higher temperatures. Referring to Figure 1B, the layer of A_x molecules is then exposed to another precursor gas containing B_y molecules. The A_x molecules react with the B_y molecules to form an extremely thin layer of solid material on the workpiece W. The chamber is then purged again with a purge gas to remove excess B_y molecules.

[0006] Figure 2 illustrates the stages of one cycle for forming a thin solid layer using ALD techniques. A typical cycle includes (a) exposing the workpiece to the

first precursor A_x, (b) purging excess A_x molecules, (c) exposing the workpiece to the second precursor B_y, and then (d) purging excess B_y molecules. In actual processing, several cycles are repeated to build a thin film on a workpiece having the desired thickness. For example, each cycle may form a layer or partial layer having a thickness of approximately 0.1-1.0Å, and thus several cycles are required to form a solid layer having a thickness of approximately 60Å.

[0007] Figure 3 schematically illustrates a single-wafer ALD reactor 10 having a reaction chamber 20 coupled to a gas supply 30 and a vacuum 40. The reactor 10 also includes a heater 50 that supports the workpiece W and a gas dispenser 60 in the reaction chamber 20. The gas dispenser 60 includes a plenum 62 operably coupled to the gas supply 30 and a distributor plate 70 having a plurality of holes 72. In operation, the heater 50 heats the workpiece W to a desired temperature, and the gas supply 30 selectively injects the first precursor A_x, the purge gas, and the second precursor B_y, as shown above in Figure 2. The vacuum 40 maintains a negative pressure in the chamber to draw the gases from the gas dispenser 60 across the workpiece W and then through an outlet of the reaction chamber 20.

[0008] One drawback of ALD processing is that it has a relatively low throughput compared to CVD techniques. For example, each A_x-purge-B_y-purge cycle can take several seconds. This results in a total process time of several minutes to form a single thin layer of only 60Å. In contrast to ALD processing, CVD techniques require only about one minute to form a 60Å thick layer. The low throughput of existing ALD techniques limits the utility of the technology in its current state because ALD may be a bottleneck in the overall manufacturing process.

[0009] Another drawback of ALD and pulsed CVD processing is the downtime required to service the valves that control the flow of precursor into the reaction chamber. The flow of each precursor is controlled by a single, quick-action valve that actuates at least once per cycle to provide the precursor to the gas dispenser. For example, the valves can actuate between 100-2000 times to build

a single 200Å thick layer. Accordingly, the high frequency of actuations causes the valves to wear out relatively quickly. Replacing and servicing these valves requires downtime, increases operating costs, and causes an associated reduction in throughput. Therefore, there is a significant need to reduce the downtime for servicing components in CVD and ALD reactors.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] Figures 1A and 1B are schematic cross-sectional views of stages in ALD processing in accordance with the prior art.

[0011] Figure 2 is a graph illustrating a cycle for forming a layer using ALD techniques in accordance with the prior art.

[0012] Figure 3 is a schematic representation of a system including a reactor for depositing material onto a microfeature workpiece in accordance with the prior art.

[0013] Figure 4 is a schematic representation of a system for depositing material onto a microfeature workpiece in accordance with one embodiment of the invention.

[0014] Figure 5 is a schematic isometric view of a valve assembly for use in the system shown in Figure 4 in accordance with another embodiment of the invention.

[0015] Figure 6 is a schematic side cross-sectional view of a valve assembly for use in the system shown in Figure 4 in accordance with yet another embodiment of the invention.

DETAILED DESCRIPTION

A. Overview

[0016] The following disclosure describes several embodiments of systems and methods for depositing material onto microfeature workpieces in reaction chambers. Many specific details of the invention are described below with reference to single-wafer reactors for depositing material onto microfeature workpieces, but several embodiments can be used in batch systems for

processing a plurality of workpieces simultaneously. The term "microfeature workpiece" is used throughout to include substrates upon which and/or in which microelectronic devices, micromechanical devices, data storage elements, read/write components, and other features are fabricated. For example, microfeature workpieces can be semiconductor wafers such as silicon or gallium arsenide wafers, glass substrates, insulative substrates, and many other types of materials. Furthermore, the term "gas" is used throughout to include any form of matter that has no fixed shape and will conform in volume to the space available, which specifically includes vapors (i.e., a gas having a temperature less than the critical temperature so that it may be liquefied or solidified by compression at a constant temperature). Several embodiments in accordance with the invention are set forth in Figures 4-6 and the following text to provide a thorough understanding of particular embodiments of the invention. A person skilled in the art will understand, however, that the invention may have additional embodiments, or that the invention may be practiced without several of the details of the embodiments shown in Figures 4-6.

[0017] One aspect of the invention is directed to a system for depositing material onto a microfeature workpiece in a reaction chamber. In one embodiment, the system includes a gas supply assembly having a first gas source, a first gas conduit coupled to the first gas source, a first valve assembly, a reaction chamber, and a gas distributor carried by the reaction chamber. The first valve assembly includes first and second valves that are in fluid communication with the first gas conduit. The first and second valves are configured in a parallel arrangement so that the first gas flows through the first valve and/or the second valve.

[0018] In one aspect of this embodiment, the system further includes a controller configured to operate the first and second valves simultaneously or in an alternating sequence. In another aspect of this embodiment, the first valve assembly further includes first and second gas passageways in fluid communication with the first gas conduit. The first valve can be configured to

control the first gas flow through the first passageway, and the second valve can be configured to control the first gas flow through the second passageway. In another aspect of this embodiment, the first valve assembly further includes a third valve in fluid communication with the first gas conduit. The first, second, and third valves can be arranged symmetrically so that the first, second, and third valves are spaced apart from a portion of the gas distributor by at least approximately the same distance.

[0019] In another embodiment, the system includes a gas supply assembly having a first gas source, a first gas conduit coupled to the first gas source, a first valve and a second valve each in fluid communication with the first gas conduit, a reaction chamber, and a gas distributor carried by the reaction chamber. The first and second valves are operable independently to individually and/or jointly provide pulses of the first gas downstream from the first and second valves. The gas distributor is in fluid communication with the first and second valves to receive the pulses of the first gas.

[0020] In another embodiment, the system includes a gas supply assembly having a first gas source, a first gas conduit coupled to the first gas source, a valve assembly, a reaction chamber, and a gas distributor carried by the reaction chamber. The valve assembly includes a body with first and second gas passageways, a first valve stem configured to control the flow of the first gas through the first gas passageway, and a second valve stem configured to control the flow of the first gas through the second gas passageway. The first and second gas passageways are in fluid communication with the first gas conduit and are configured in a parallel arrangement.

[0021] Another aspect of the invention is directed to a method of depositing material onto a microfeature workpiece in a reaction chamber. In one embodiment, the method includes flowing a first pulse of a first gas through a first gas conduit and a first valve into the reaction chamber. The method further includes flowing a second pulse of the first gas through the first gas conduit and a second valve into the reaction chamber without flowing the second pulse of the

first gas through the first valve. In one aspect of this embodiment, flowing the first pulse of the first gas includes controlling the first valve to dispense the first pulse of the first gas into the reaction chamber, and flowing the second pulse of the first gas includes controlling the second valve to dispense the second pulse of the first gas into the reaction chamber.

B. Deposition Systems

[0022] Figure 4 is a schematic representation of a system 100 for depositing material onto a microfeature workpiece W in accordance with one embodiment of the invention. In this embodiment, the system 100 includes a reactor 110 having a reaction chamber 120 coupled to a gas supply 130 and a vacuum 140. The reactor 110 also includes a gas distributor 160 coupled to the reaction chamber 120 and the gas supply 130 to dispense gas(es) into the reaction chamber 120 and onto the workpiece W.

[0023] The gas supply 130 includes a plurality of gas sources 132 (identified individually as 132a-c) and a plurality of upstream main lines 136 coupled to the gas sources 132. The gas sources 132 can include a first gas source 132a for providing a first gas, a second gas source 132b for providing a second gas, and a third gas source 132c for providing a third gas. The first and second gases can be first and second precursors, respectively. The third gas can be a purge gas. The first and second precursors are the gas and/or vapor phase constituents that react to form the thin, solid layer on the workpiece W. The purge gas can be a suitable type of gas that is compatible with the reaction chamber 120 and the workpiece W. In other embodiments, the gas supply 130 can include a different number of gas sources 132 for applications that require additional precursors or purge gases. In additional embodiments, the gas sources 132 can include one or more etchants for deposition onto a microfeature workpiece during etching.

[0024] In the illustrated embodiment, the reactor 110 also includes a workpiece support 150 to hold the workpiece W in the reaction chamber 120. In one aspect of this embodiment, the workpiece support 150 can be heated to bring the workpiece W to a desired temperature for catalyzing the reaction between the first

gas and the second gas at the surface of the workpiece W. For example, the workpiece support 150 can be a plate with a heating element. The workpiece support 150, however, may not be heated in other applications.

[0025] The system 100 of the illustrated embodiment further includes a plurality of valve assemblies 168 (identified individually as 168a-c) coupled to the upstream main lines 136 and a plurality of downstream main lines 139 coupled to the valve assemblies 168 and the gas distributor 160. The valve assemblies 168 can include a plurality of branch lines 137 (identified individually as 137a-b) attached to the upstream and downstream main lines 136 and 139 and a plurality of valves 170 (identified individually as 170a-b) attached to the branch lines 137. The branch lines 137 flow the gases from the upstream main lines 136 to the downstream main lines 139, and the valves 170 control the flow of the gases through the branch lines 137. In the illustrated embodiment, the first and second valves 170a-b are configured in a parallel arrangement, and accordingly, each portion of gas flows through either the first valve 170a or the second valve 170b of the corresponding valve assembly 168. In other embodiments, such as those described below with reference to Figures 5 and 6, the valve assemblies can have a different configuration and/or a different number of valves. For example, several valve assemblies 168 can be combined into a single valve assembly, and/or the valve assemblies 168 can be carried by the reaction chamber 120.

[0026] The valve assemblies 168 are operated by a controller 142 that generates signals for controlling the flow of gases into the reaction chamber 120 for ALD and CVD applications. For example, the controller 142 can be programmed to operate the valve assemblies 168 to pulse the gases individually through the gas distributor 160 in ALD applications or mix selected precursors in the gas distributor 160 in CVD applications. More specifically, in one embodiment of an ALD process, the controller 142 actuates the first valve 170a of a first valve assembly 168a to dispense a pulse of the first gas (e.g., the first precursor) into the reaction chamber 120. Next, the controller 142 actuates the first valve 170a of a third valve assembly 168c to dispense a pulse of the third gas (e.g., the purge

gas) into the reaction chamber 120. The controller 142 then actuates the first valve 170a of a second valve assembly 168b to dispense a pulse of the second gas (e.g., the second precursor) into the reaction chamber 120. Next, the controller 142 actuates the second valve 170b of the third valve assembly 168c to dispense a pulse of the third gas into the reaction chamber 120. In the next cycle, the process is repeated except the controller 142 actuates the second valves 170b (rather than the first valves 170a) of the first and second valve assemblies 168a-b to dispense pulses of the first and second gases into the reaction chamber 120.

[0027] In one embodiment of a pulsed CVD process, the controller 142 actuates the first valves 170a of the first and second valve assemblies 168a-b to dispense a pulse of the first and second gases (e.g., the first and second precursors) into the reaction chamber 120. Next, the controller 142 actuates the first valve 170a of the third valve assembly 168c to dispense a pulse of the third gas (e.g., the purge gas) into the reaction chamber 120. In the next cycle, the controller 142 actuates the second valves 170b (rather than the first valves 170a) of the first and second valve assemblies 168a-b to dispense a pulse of the first and second gases into the reaction chamber 120. The controller 142 then actuates the second valve 170b of the third valve assembly 168c to dispense a pulse of the third gas into the reaction chamber 120. In other embodiments, the controller 142 can actuate the valves 170 in other sequences.

[0028] One feature of the illustrated embodiment is that each gas source is coupled to a valve assembly with a plurality of valves. By coupling several valves to each gas source, the frequency with which each valve is actuated to dispense gas is reduced. For example, if each gas source is coupled to a valve assembly with two valves, the frequency that each valve is actuated may be reduced by one half. One advantage of this feature is that the life of the valve assembly is extended because the valves do not wear out as quickly. When the valves wear out or otherwise fail, the system is shut down to replace and/or service the valves.

Accordingly, the system of the illustrated embodiment reduces the downtime to replace and/or service the valves and thereby increases the throughput.

[0029] In other embodiments, the controller 142 can simultaneously actuate the first and second valves 170a-b of a single valve assembly 168 to dispense a portion of the corresponding gas into the reaction chamber 120. One advantage of this arrangement is that if one valve fails, the other valve in the valve assembly will continue to dispense gas for deposition onto the workpiece W.

C. Other Valve Assemblies

[0030] Figure 5 is a schematic isometric view of a valve assembly 268 for use in the system 100 shown in Figure 4 in accordance with another embodiment of the invention. The valve assembly 268 includes a plurality of valves 270 (identified individually as 270a-c) and a plurality of branch lines 237 (identified individually as 237a-c) coupling the valves 270 to the upstream and downstream main lines 136 and 139. In one aspect of this embodiment, the branch lines 237 and the valves 270 are arranged symmetrically so that the valves 270 provide pulses of gas to the reaction chamber 120 (Figure 4) at a consistent pressure and with a consistent response time. For example, the branch lines 237 can include a first portion 243 coupled to the upstream main line 136, a second portion 244 coupled to the first portion 243 and the valve 270, a third portion 245 coupled to the valve 270, and a fourth portion 246 coupled to the third portion 245 and the downstream main line 139. The first portions 243 can be oriented at generally the same angle relative to the upstream main line 136, and the fourth portions 246 can be oriented at generally the same angle relative to the downstream main line 139. The second and third portions 244 and 245 can be generally parallel to the upstream and downstream main lines 136 and 139. Moreover, the portions 243, 244, 245 and 246 in each branch line 237 can have approximately the same length as the corresponding portions in the other branch lines 237. In this embodiment, the symmetric arrangement can ensure that each valve 270 provides consistent and uniform pulses of gas to the reaction chamber 120 (Figure 4). In other embodiments, the valve assembly 268 may have other configurations,

including asymmetric arrangements. For example, the valve assembly can include a body with gas passageways, such as in the embodiment described below with reference to Figure 6, or the valve assembly can include a different number of valves.

[0031] Figure 6 is a schematic side cross-sectional view of a valve assembly 368 for use in the system 100 shown in Figure 4 in accordance with another embodiment of the invention. The valve assembly 368 includes a valve body 372 having a first gas passageway 338a and a second gas passageway 338b, a first valve stem 380a in the valve body 372, and a second valve stem 380b in the valve body 372. The valve body 372 includes an inlet 374 configured for attachment to the upstream main line 136 (Figure 4), an outlet 376 configured for attachment to the downstream main line 139 (Figure 4), a plurality of valve seats 383, and a plurality of cavities 378. The first and second valve stems 380a-b include a first portion 381 configured to engage the valve seat 383 and a second portion 382 configured to be received in the cavity 378. The first and second valve stems 380a-b are movable in a direction D between a first position (illustrated by the first valve stem 380a) in which the first portion 381 engages the valve seat 383 and a second position (illustrated by the second valve stem 380b) in which the second portion 382 is received in the cavity 378. The position of the first and second valve stems 380a-b controls the flow of gas through the gas passageways 338.

[0032] In operation, a gas flow "F" enters the valve body 372 through the inlet 374 and is split into two separate flows at a junction 347 of the first and second gas passageways 338a-b. The first and second gas passageways 338a-b are configured in a parallel arrangement so that each portion of gas flows through either the first gas passageway 338a or the second gas passageway 338b. When one or both of the valve stems 380a-b are in the second position, the gas flows past the valve stems 380a-b and exits the valve body 372 through the outlet 376. In one embodiment, a controller can actuate the valve stems 380 in an alternating sequence so that when one valve stem 380 is in the second position, the other

valve stem 380 is in the first position. In other embodiments, a controller can actuate the valve stems 380 simultaneously so that both of the valve stems 380 can be in the second position at the same time. In additional embodiments, the valve assembly 368 can include a different number of valve stems 380 and gas passageways 338. For example, a valve assembly can include four gas passageways and four valve stems.

[0033] From the foregoing, it will be appreciated that specific embodiments of the invention have been described herein for purposes of illustration but that various modifications may be made without deviating from the spirit and scope of the invention. Accordingly, the invention is not limited, except as by the appended claims.